

REMOTE SENSING OF HYDROLOGIC VARIABLES IN BOREAL AREAS**FINAL REPORT - PHASE 2****May 1995**

*Final
11-12-95
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p. 28*

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(NASA-CR-198717) REMOTE SENSING OF
HYDROLOGIC VARIABLES IN BOREAL
AREAS, PHASE 2 Final Report, Apr.
1994 - Apr. 1995 (Hydex Corp.)
28 p

N95-27998

Unclass

G3/43 0049979

REMOTE SENSING OF HYDROLOGIC VARIABLES IN BOREAL AREAS

ANNUAL REPORT - PHASE 2

May 1995

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EXECUTIVE SUMMARY

Airborne Gamma Radiation measurements were conducted in September 1993 and during IFC-2 and IFC-3 in 1994 over 48 BOREAS flight lines in support of projects by Hyd-6 and Hyd-4. Ground measurements of the soil moisture (SM) of the mineral soil and of the depth and water content (WC) of the moss/humus layer were collected for calibration of the flight lines. Airborne surveys were flown during the winter IFC-W in February 1993 and 1994 and ground measurements of the water equivalent (WE) of the snow cover were obtained by Hyd-4.

Techniques for measuring the WC of the moss/humus layer were developed (by Hyd-6 and Hyd-4) in September 1993 near the OBS tower site in the southern study area (SSA) and in-situ observations were obtained at this site in July, August and September 1994. Special attention, including repeated ground observations, has been given to the flight lines over, and near, the primary tower sites in the SSA; Old Black Spruce (OBS), Old Jack Pine (OJP), Old Aspen (OA) and Young Aspen (YA). In flight videos of the BOREAS flight lines were taken several times during the various gamma radiation surveys.

All ground data, airborne estimates and locations of flight lines and ground

sampling points have been submitted to BORIS (Boreas Information System).

Multiple ground surveys show the variation of the water content of the moss/humus layers and changes in the amount of standing water near the OBS tower (SSA) during the period September 1993 to September 1994.

During the last three flight days in September 1994, exceptionally high values of cosmic radiation were observed by the up looking detectors of the airborne gamma radiation system. A paper on the observations of the high cosmic radiation was presented at the BOREAS workshop in Ellicott City, MD, in March 1995. Follow up investigation has not determine the source of, or what caused, the high cosmic count rates.

GROUND OPERATIONS

The primary purpose of the Hyd-6 study is to measure and define soil moisture (SM) in the BOREAS study area. Due to limitations in funding the soil moisture study has been mainly limited to the area in the SSA outlined in Figure 1. Ground in-situ measurements of the SM of the mineral soil and of the depth and WC of the moss/humus layer were made along all BOREAS flight lines in the SM study area. In-situ samples were collected for approximately 800 locations along 42 of the 48 established flight lines. One or more soil samples were obtained at most sites for a 20 cm depth (or for the depth of the soil if less than 20 cm). The percentage of SM by weight was determined by the gravimetric method.

Where a moss/humus layer of 5 cm or more in depth exists, measurements of the water content of the moss/humus layer were obtained using an ESC snow tube (30 sq cm), when available, and the WC was computed using the gravimetric method.

FLIGHT LINES

The flight lines originally established for the northern study area (NSA) and along the Transect between the NSA and the SSA are the same as described in Version 3.0 of the BOREAS Experimental Plan (Figure 5.2.1.4a and Figure 5.2.1.4b). Changes and additions were made in the flight lines for the SSA. The final flight lines in the SSA are shown in Figure 1. Flight line BP101 was discontinued and flight lines BP122 and BP123 were added at the request of other BOREAS scientists. BP122 was discontinued when ground and airborne observations showed the vegetative cover along the flight line as extremely heterogenous. Flight line BP123 was established

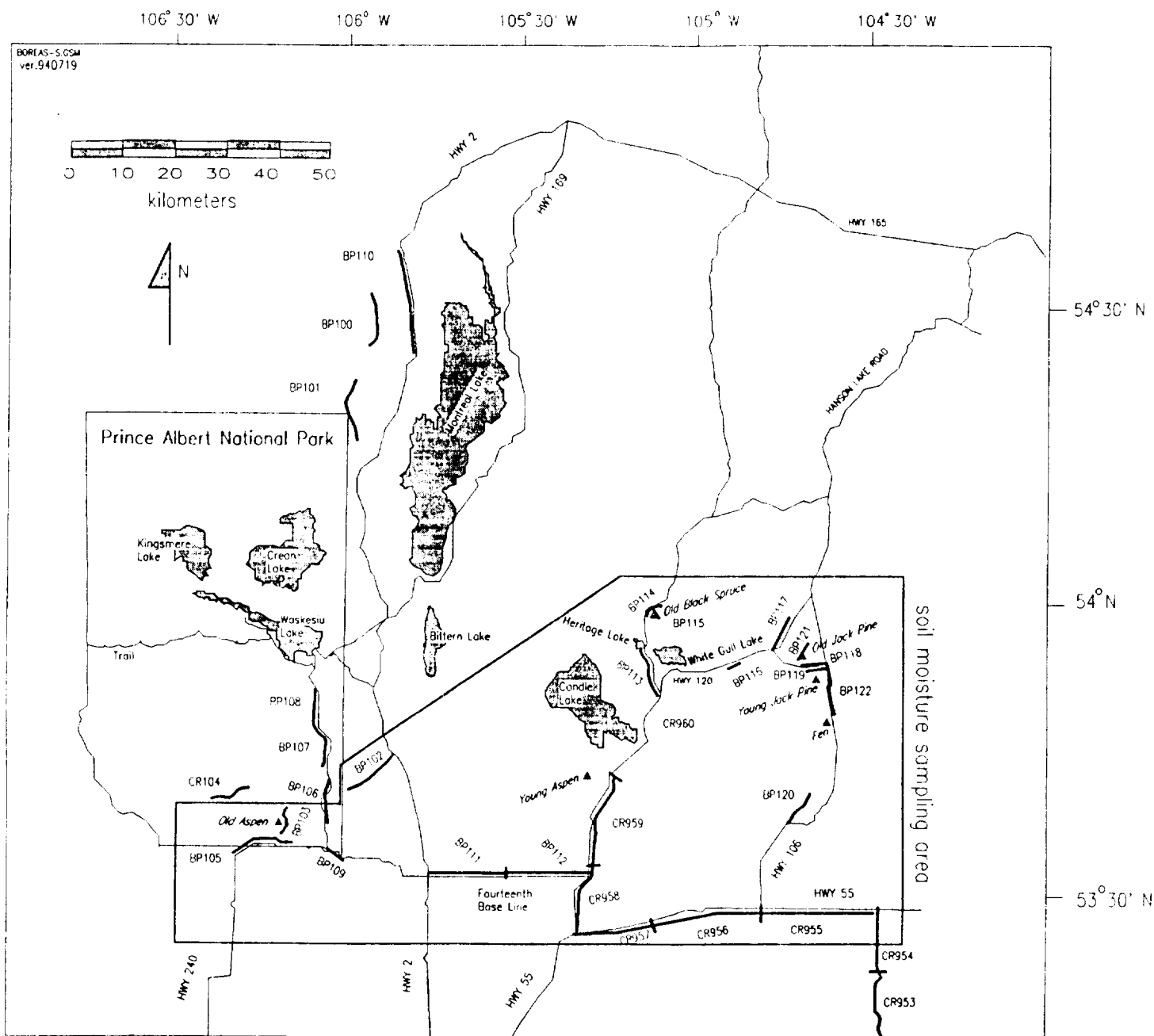


FIGURE 1 BOREAS Southern Study Area
Flight Lines and area of intensive soil moisture sampling

over the YA (SSA) tower site with the assistance of those operating the YA Tower.

The 48 BOREAS flight lines have been divided into 158 bins (sections) with two to six bins per flight line to provide additional information on the distribution of the SM, WC of the moss/humus layer and the WE of the snow cover. Information on the number of flight lines and bins for each area are shown in Table 1.

Table 1

Number and average coverage of flight lines and bins of flight lines

Category	Number of Flight Lines	Average Length km	Average Areal km ²	Number of Bins	Average Length km	Average Areal km ²
BP100- BP123 (SSA)	24	8.0	2.4	80	2.4	0.7
CR954- CR960 (SSA)	7	16.1	4.9	24	4.7	1.4
BP201- BP213 (NSA)	13	10.3	3.1	33	4.0	1.2
BP301- BP305 (Transect)	5	17.0	5.2	15	5.7	1.7

Ground calibration data have been collected for all flight lines in the SSA except flights lines BP104 and BP110 which are not accessible except by overland vehicles. These two flight lines are not in the soil moisture study area. The calibration data estimated for these two lines are considered reliable. Calibration data for the 158 bins (SM plus WC) have been computed and used in computing airborne estimates of SM.

Airborne radiation measurements were collected in the NSA prior to conducting surveys in the SSA on 27 July 1994. A ground crew furnished by Hyd-4 collected calibration data (SM and WC) for some of the NSA and Transect flight lines

AIRBORNE GAMMA RADIATION TECHNIQUES

For the benefit of those who may not be familiar with the National Weather Service (NWS) airborne gamma radiation system used in this study, a brief description and comments on the use of the system follows. The system consists of five downward, and two upward looking, sodium iodine (NaI) thallium (TI) detectors, an associated pulse height analyzer, a mini-computer system, and temperature, pressure and radar altitude sensors as described by Carroll and Vadnais (1980). The spectral radiation data obtained by the system are used to compute the gamma fluxes for three radiation windows; the ^{40}K window (1.26 - 1.56 MeV), the ^{208}Tl window (2.41 - 2.81 MeV) and the gross count (GC) energy spectrum (0.41 - 3.0 MeV).

The concentration of radioisotopes in the ground is essentially constant with time (Zotimov, 1968). Therefore, it is necessary to measure the ground soil moisture and establish background radiation by airborne surveys for the three radiation windows only once to calibrate a specific flight line. The airborne flight line measurement of soil moisture is considered to be a measurement of an area rather than a single line. The width of a flight line measurement has been accepted as 305 m; thus a measurement for a single BOREAS flight line of 6.2 km represents an areal measurement for an area of 1.9 km².

The NWS's soil moisture estimates for a flight line are the weighted average of

estimates determined using data from the three spectral radiation windows. The weights are; (1) 0.346 for the ^{40}K window, (2) 0.518 for the ^{208}Tl window, and (3) 0.136 for the GC. These weights were derived from a 10-year historical data base of simultaneous ground measurements of soil moisture and airborne radiation data [Carroll and Allen, 1988]. The techniques used by the NWS system to measure soil moisture are discussed by Carroll and Allen [1988] and by Jones and Carroll [1983].

There are a number of possible sources of random and systematic errors in the airborne soil moisture measurements. One error results from random fluctuations in the radiation data as a result of the nature of the radioactive decay process [Knoll, 1979], resulting in "counting statistics errors." Two other sources of error are; (1) those associated with the ground measurements of soil moisture data used for calibration, and (2) those accounting for the airmass between the aircraft and the ground which absorbs a large portion of the emitted gamma radiation. A fourth source of error results from calculations to compensate for extraneous sources of radiation and scattering with the gamma spectrum, as discussed by Fritzsche [1979].

The counting statistics errors of the airborne soil moisture estimates can be reduced if the data acquisition time is increased. The acquisition time for a flight line is dependent on the speed of the aircraft and the length of the line. Since the air speed of the aircraft is nearly constant, the length of the line is a major factor in determining the acquisition time. Repeated flights over the same line is one way to increase the acquisition time and to improve the accuracy of the airborne estimates.

The gamma radiation measured in the ^{208}Tl radiation window is less subject to extraneous sources of radiation and scattering within the gamma spectrum than the

measurement in the ^{40}K radiation window [Carroll and Allen, 1988]. Both of these windows are much less subject to these sources of error than the GC window. The total count in the GC window, however, is typically an order of magnitude greater than the counts experienced in the ^{40}K and the ^{208}Tl windows, and therefore much less subject to "counting statistic errors."

AIRBORNE ESTIMATES OF TOTAL MOISTURE

The airborne gamma radiation estimates in the boris file (Airestsm.DAT) represent the averages of the total moisture (in percent by dry weight of the mineral soil) along the flight lines or bins. For those lines that have a moss/humus layer on the ground, the total moisture represent the soil moisture and the water content of the moss/humus layer (converted from cm of water to percent of soil moisture). For those flight lines (and bins) that may also have standing water (i. e., flight line BP115 near OBS) the amount of standing water (cm) is also included in the estimated total moisture from the airborne gamma radiation measurements.

For a calibrated flight line a knowledge, or estimate, of the current SM of the mineral soil permits the measurement of the WC of the moss/humus layer. When there is a snow cover, measurements of the WE of the snow cover require a knowledge of the WC of the moss/humus layer along with a knowledge of the SM of the mineral soil.

The BOREAS data set provides information on adapting existing airborne radiation measuring procedures for measurement of the WC of the moss/humus layer. The data set also provide for improving measurements of the WE of the snow cover by accounting for the attenuation of the gamma radiation emitted from the mineral soil by

the WC of the moss/humus layer.

SPECIAL MEASUREMENTS NEAR TOWER SITES (SSA)

Multiple ground measurements have been obtained for the primary tower sites in the SSA. These are flight lines BP115 (OBS), BP103 (OA), and BP121 (OJP). Flight line BP103 was established near the Old Aspen (OA) on 5 September 1994 but time did not permit a second ground survey.

Old Black Spruce

Four sets of measurements were made near the OBS SSA tower site and three sets of in-situ measurements along Bin 3 of the flight line. Bin 3 extends one km from near the OBS tower to the west north west (309 degrees magnetic).

On 9 September 1993 measurements were made near the OBS tower site and the technique developed for measuring the WC of the moss/humus layer (described in the Phase 1 annual report). The road to the OBS tower site along the boardwalk was practically a swamp. The entire area of the heavy black spruce had considerable amounts of standing water. Figure 2 is a picture taken along the entrance road on 8 September 1993 to the OBS tower site.

Measurements were also obtained near the OBS tower site on three days in 1994 and measurements were made along Bin 3. Table 2 is a listing of the measurements of the SM of the mineral soil and of the WC of the moss/humus layer for the four days.



Figure 2 Trail to Old Black Spruce, September 1993. Extremely wet.



Figure 3 Trail to Old Black Spruce, September 1994. Completely dry..

Table 2

Measurements at and near OBS Tower

Date	____Near OBS Tower____		____Along Bin 3____	
	SM, %	WC, cm	SM, %	WC, cm
9 Sep 1993	21.2	1.6	-	-
28 Jul 1994	20.1	3.0	23.9	4.1
3 Aug 1994	16.3	3.3	34.8	5.4
3 Sep 1994	14.9	2.2	16.3	4.9

The SM of the mineral soil decreased from September 1993 to September 1994 but there was no appreciable change in the WC of the moss/humus layer. Airborne estimates of the total moisture (in percent of SM) decreased from 97.7 percent in September 1993 to 51.5 percent on September 1994)..

The entire area of Old Black Spruce dried out during the year. In July and August 1994 there was a noticeable decrease in the standing water along the road and along Bin 3. On 3 September 1994 the road was completely dry and no standing water observed along Bin 3. Figure 3 is a picture of the road into the tower site on 3 September 1995, clearly indicating the very unusual dry conditions.

Old Jack Pine

Ground sampling was conducted along flight line BP121 over the OJP SSA tower site on 29 July 1994 and 2 September 1994. The SM of the mineral soil decreased from 5.5 percent to 3.0 percent during the interval. The decrease in the SM over that observed at OBS tower site can be attributed to the much less

moss/humus layer in the OJP area. The WC of the moss/humus layer in the OJP area decreased from 0.5 cm to 0.05 cm from July to August.

Old Aspen

In-situ measurements were conducted along the north-south flight line BP103 that is centered over the entrance road to the OA SSA tower site on 9 September 1993 (by members of Hyd-4) and on 5 September 1994 (by members of Hyd-6).

Precipitation was greater in this area than over the OBS and OJP tower sites during the period from September 1993 to September 1994 and there was little change in the average SM for the line (from 12.4 percent to 12.2 percent). No moss/humus layer was observed along flight line BP103.

Young Aspen

The flight line established over the YA tower site in the SSA has two bins with different vegetative conditions. Bin 1 is over the tower site and has only YA with a humus layer (no moss) that averages 9.6 cm in depth. On 5 September, when the line was established, the average WC was 1.7 cm. Vegetation along Bin 2 consists only of OA with no moss/humus layer. Measurements of the WC of the light litter showed very little water content.

The soil moisture average values for both Bin 1 and Bin 2 on 5 September were almost the same; 10.7 percent for Bin 1 and 10.9 percent for Bin 2. During the next six days when airborne surveys were made over the flight line the humus layer protected the SM along Bin 1 but the SM in the OA decreased as shown in Figure 4. The total moisture measurements are shown on Figure 4 but the relative amount of moisture in the soil and in the humus is probably fairly constant.

Old Aspen Tower SSA, Total Moisture SM plus WC

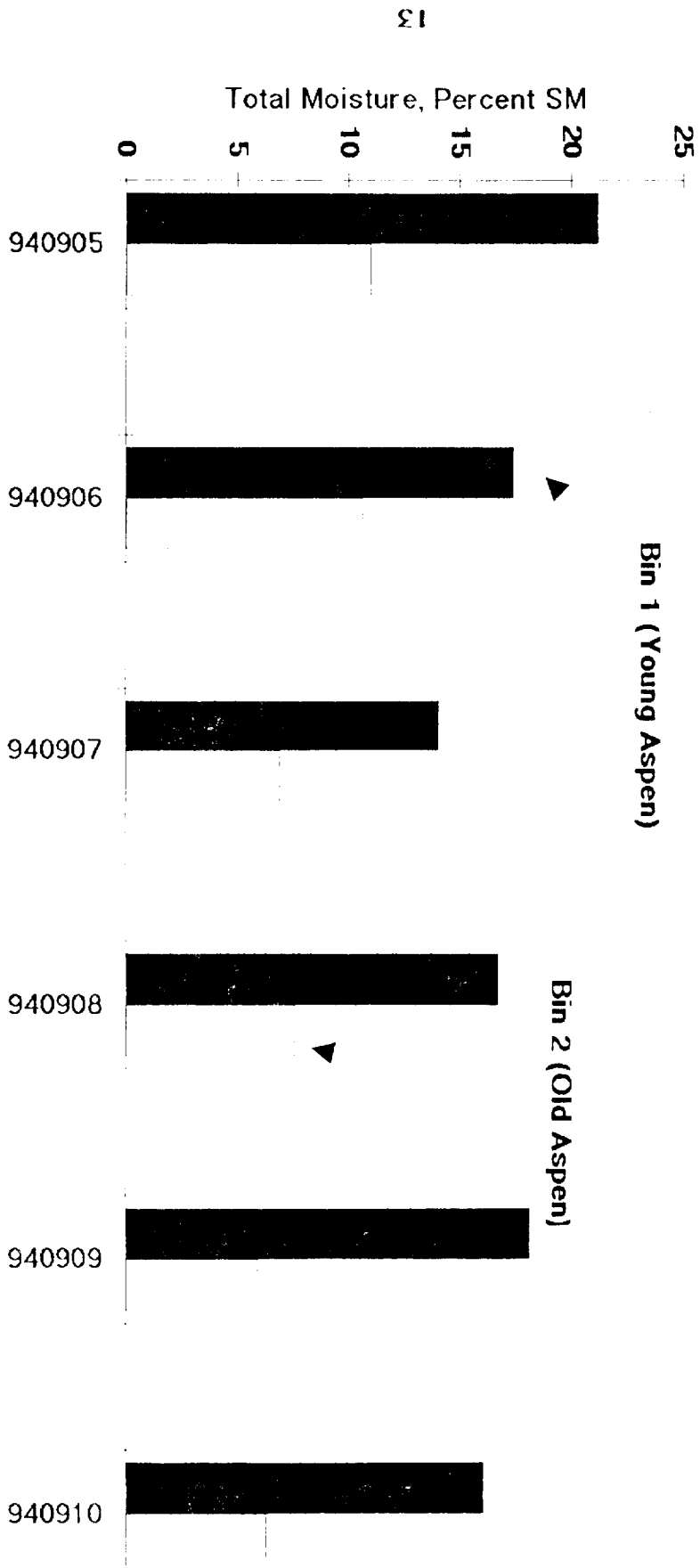


Figure 4 Airborne estimates of SM, Flight line BP123, 5-10 September 1994.

HIGH COSMIC RADIATION

During the last three days of airborne gamma radiation measurements over the SSA, 8-10 September 1984, extremely high cosmic radiation was observed. The up looking cosmic radiation detectors, 3.0 to 5.12 mev, received exceptionally high counts. The occurrence of the high cosmic radiation was reported at the Ellicott City BOREAS workshop in the paper "High Cosmic Radiation in BOREAS Area" by Peck and Carroll (1995). copy attached. The high cosmic radiation has engendered considerable interest by many agencies interested in such phenomena but to date no scientist has been able to identify or explain the high measurements. Many scientists and organizations have been contacted to obtain additional information about the high cosmic measurements including the following:

Jack Trombka and Sam Young, NASA, Goddard Space Flight Center

James Kurfess, Navy Research Laboratory, Space Science Division

Bob Reading, Los Alamos, New Mexico

Denise Traver, Department of Defense, Pentagon

David Evans and Joe Konches, Space Environment Laboratory, NOAA
Boulder, Colorado

All of the above have shown the paper on the High Cosmic Radiation to other scientists in their agencies who have knowledge of cosmic radiation. Each one reported considerable interest but no answers. A very complete analyses of what could possibly be the cause of the high measured radiation was furnished by David Evans of the NOAA Boulder, CO, office that investigates unusual occurrences of cosmic radiation. Evans started with the presumption that our radiation detectors

were counting radiation that originated from the top of the atmosphere and eliminated four possibilities; Auroral particles, Galactic cosmic rays, Solar Protons, and Very energetic electrons. He concluded that there was no source of radiation from space that could account for the responses registered by the detectors. He concluded with the comment “. . . We would suggest that the source of the radiation that you encountered during these flights is lightly local to the area, either in the atmosphere (radio-active debris) or on the ground.” Evans also provided information (plots) on the Daily Electron Fluence from GOES7 and on Cosmic Ray Indices from the Neutron Monitor. Neither of these measurements showed any unusual activity for September 1994. Bob Reading, Los Alamos, New Mexico, who has access to almost all satellite measurements was unable to find any evidence of unusual activity. during the period 8-10 September 1994.

Efforts to determine the source of the radiation is continuing and we have been encouraged to publish the occurrence in an publication that would be available to scientists working with cosmic radiation.

REVISED METHOD FOR COMPUTING SOIL MOISTURE

The radiation measurements from the up-looking cosmic detectors are used to correct the Gross Count window measurements for cosmic radiation effects. With the unusually high counts (1400 cpm compared to a normal of less than 200 cpm) over portions of the SSA on 8th and 9th of September 1994 and over the entire SSA on 10 September 1994 rendered the use of the Gross Count for measuring the soil moisture unfeasible. The computed airborne estimates of soil moisture were negative for the

SSA areas having high cosmic radiation when standard NWS weights for the three radiation windows (^{40}K , ^{208}Tl and GC) were used for 8-10 September 1994.

During the FIFE experiment in Kansas a technique was developed for measuring soil moisture over short flight lines (Peck et al. 1990). The weighing factors for these short flight lines used only the ^{40}K and ^{208}Tl radiation windows. Estimates using the standard NWS weights for all three radiation windows were compared with those using the FIFE weighing factors for only the ^{40}K and ^{208}Tl windows. For all BOREAS airborne gamma radiation estimates for flight lines without the high cosmic radiation there were essentially no difference in the two sets of estimates. Consequently all airborne estimates for the BOREAS study have been computed using the FIFE weights (^{40}K and ^{208}Tl windows only).

DOCUMENTATION FOR BORIS

The following files and documentation have been submitted to BORIS

File	Contents
Airborne.DAT	Locations of flight lines and bins
Mastergd.DATA	Ground Soil Moisture data
Mastermh.DAT	Ground Moss/humus data
Airestsm.DAT	Airborne estimates
Gammsit.DOC	Documentation for sites locations
Gammdat.DOC	Documentation for airborne estimates

COOPERATION

Continual contact has been made with Piers Sellers, Forest Hall and others of the BOREAS office at NASA Goddard, Space Flight Center, with Dennis Lettenmaier, Chairman of the BOREAS HYD group, and with members of Hyd-4 (Barry Goodison, John Metcalfe and Anne Walker of AES)

The Ellicott City BOREAS workshop provided an excellent opportunity for coordination with other BOREAS scientists. Preliminary ground measurements and airborne estimates of the total moisture have been furnished to many other BORIS scientists.

ACKNOWLEDGMENTS

Thanks are extended to Forest G. Hall, Piers J. Sellers, and others of the BOREAS staff at NASA, and to Barry Goodison and John Metcalfe of AES, Canada for their support and cooperation. Special thanks to Betsy Middleton, NASA, for her excellent support in arranging for drying ovens and for her supervision at the science center in the SSA, and to the local Canadians who did an excellent job in conducting ground surveys; Kevin Robinson, Gordon Husband, and Zak McKenzie.

REFERENCES

Carroll, T. R., and M. Allen. Airborne gamma radiation snow water measurements and soil moisture measurements and satellite areal extent of snow cover measurements: A user's guide, version 3.0, Off. of Hydrol. Natl. Wea. Serv., Minneapolis, Minn., Nov. 1988.

- Carroll, T. R., and Vadnais, K. G., Operational airborne measurements of snow water equivalent using natural terrestrial gamma radiation, in Proc. 48th Western Snow Conf., 97-106, Laramie, Wyo., 1980.
- Fritzsche, A. E., The development of an airborne gamma radiation system for snow surveys, Remote sensing of snow and soil moisture by nuclear techniques, Proc. WMO Workshop, 22-32, Voss, Norway, April 23-27, 1979.
- Jones, W. K., and T. R. Carroll, Error analysis of airborne gamma radiation soil moisture measurements, Agric. Meteorol. 28, 19-30, Amsterdam, Netherlands, 1983.
- Knoll, G. F., Radiation Detention and Measurement. John Wiley, New York, 1979.
- Peck, E. L., and T. R. Carroll, High Cosmic Radiation in BOREAS Area, paper presented at the Ellicott City, MD, BOREAS workshop on March 29-31, 1995.
- Peck, E. L., T. R. Carroll, and L. P. Lipinski, Airborne gamma radiation soil moisture measurements over short flight lines, in Symposium on FIFE, 79-84. American Meteorology Society, Boston, Mass., 1990.
- Zotimov, N. V., Investigation of a method of measuring snow storage by using gamma radiation from the Earth, Sov. Hydrol., Selec. Pap., 3, 254-266, 1968

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HIGH COSMIC RADIATION IN BOREAS AREA

by

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For Presentation at BOREAS Conference,
Ellicott City, Maryland, 29-31 March 1995

Introduction

Exceptionally high cosmic radiation was observed in the southern study area (SSA) of BOREAS during a three-day period in September 1994. The radiation values were observed during aerial surveying to measure the soil moisture along established BOREAS flight lines. Such high input of cosmic radiation is considered to be a rare event, and could affect radiation measurements by other BOREAS scientists. This report has been prepared to discuss how the radiation data were observed and to present information on the temporal and spatial variation in the cosmic radiation.

Airborne Gamma Radiation System

The National Weather Service (NWS) airborne gamma radiation system is used in the BOREAS study. For the benefit of those not familiar with the system a brief description of the NWS airborne system follows. Primarily the purpose of the NWS system is to provide information on the energy levels of gamma radiation emitted from the surface of the earth. The NWS airborne system is used by Hyd-6 of BOREAS to measure the soil moisture (SM) of the mineral soil, the water content (WC) of the moss/humus layer, and the amount of standing water (SW) and by Hyd-4 to measure the water equivalent (WE) of the snow cover. The NWS system uses two NaI(Tl) detectors. The first detector is up-looking and consists of two 10.2 x 10.2 x 20.3 cm detectors. The up-looking detector measures gamma radiation having energy levels from 3.00 to 5.12 mev. The second detector consist of five down-looking detectors of the same size. Photo multiplier tubes associated with the detectors, provide radiation data for determining a gamma energy spectrum for each survey.

Counts-per-minute (cpm) values for three radiation windows are derived from the average energy spectrum for each flight line. The radiation windows are the Potassium (40K) window (from 1.37 to 1.57 mev), the Thallium (208Tl) window (from 2.42 to 2.82 mev) and the Gross Count (GC) window (from 0.42 to 3.00 mev). The cpm data for each window, compared to background calibration data values, are used to compute estimates of the SM and WE of the snow cover and other variables. Stripping techniques are used to compute the counts in the K and Tl windows representing the number of uncolided K and Tl gamma radiation counts received by the down-looking detector that originate from the radioactive elements in the ground. The Gross count is a measure of all gammas in

its energy window. The observed GC counts from the down-looking detector are corrected for gammas produced by radon and by cosmic radiation using measurements from the up-looking detector.

The final GC values are generally fairly stable and reliable for use with the estimates from the K and TI windows in estimating SM. In some countries, that do not have the special detectors as does the NWS, only GC counts are used for determining estimates of the SM or the WE of the snow cover.

The standard NWS procedure is to use weighted values of the K, TI and GC corrected counts to determine final SM and WE estimates. During analyses of the BOREAS airborne radiation data, using the standard NWS weights, very high cosmic counts from the up-looking detector resulted in estimates of negative soil moisture for some of the flight lines during the three days in September 1994. For these particular days the in-situ SM was the lowest observed during the BOREAS study.

During the FIFE experiment conducted near Manhattan, Kansas in 1987 and 1989, revised weighting factors for short flight lines were developed using only the K and TI windows for estimating SM. The revised FIFE weights have been used to calculate SM estimates for all BOREAS surveys. Thus, the high cosmic radiation readings do not affect the BOREAS estimates of SM. The computed estimates of SM using the revised FIFE weights correlate well with those computed using the standard NWS weights (including the GC window) except for the three-day period in September 1994.

High Cosmic Radiation Values

In the BOREAS SSA there are 24 flight lines for the soil moisture measurement program by Hyd-6 (these flight lines and others are used for the snow measurement program by Hyd-4) The 24 flight lines are divided into 90 segments (bins) to provide measurements on a smaller scale. Not all lines are measured each day during field operations. Special attention is given to those flight lines established over or near the primary BOREAS tower sites.

For three days in September 1994 (8th - 10th) many of the cosmic radiation measurements from the up-looking detector for segments of flight lines (bins) in the SSA were significantly greater than all other measurements made during BOREAS. Table 1 is a summary of all up-looking detector counts-per-minute observed during the entire BOREAS study (including measurement over the northern study area and along the transect between the two areas). The first three columns of numbers are those recorded over the SSA by the up-looking detector for the three days in September 1994 when the high radiation was observed. On 8 September 41 bins were surveyed. Of these 24 had high cosmic counts that averaged 1,389 with a standard deviation of 63.9. On 9 September 51 bins were surveyed in the SSA and 30 had cosmic counts that averaged

1,420 with a standard deviation of 37.9. On both days a couple of flight lines with high cosmic values also had 1 or more bin values that were less, but higher (about 500 counts-per-minute) than values for other flight lines that averaged only slightly more than 200 cpm.

On 10 September 40 bins were surveyed and high cosmic radiation cpm (averaged 1,383 with a standard deviation of 40.8) were observed for all bins in the entire SSA. The high counts on these three days contrast sharply with the average cpm of 188 (standard deviation of 20.3) for all other BOREAS measurements (1,643 bins).

Aerial Extent of High Cosmic Radiation

Airborne surveys were conducted over the SSA during September 1993, February 1994, and during July, August and September 1994. No high radiation values were observed for any bin of any flight line in the entire BOREAS study area prior to 8 September. Figure 1 shows the SSA area of BOREAS that had high cosmic radiation on 8 September. For some flight lines, i. e., BP102 immediately east of Prince Albert National Park, only 4 of the 5 flight line bins had high radiation values providing fairly precise information on the edge of the high radiation. In the area just east of Candle Lake flight lines CR960 and BP113 had all high values on 8 September and BP114 just to the north had only low values.

The area of high cosmic radiation increased by 9 September, Figure 2. The high value area included part of additional northern flight lines (BP114, BP117) and extending south and to the east of flight line CR960. However, flight line BP113 to the north of CR960 changed from high to low values.

On 10 September every measured bin in the SSA had high cosmic radiation. No airborne gamma radiation measurements are available after 10 September.

Accuracy and Consistency of Measurements

When very unusual measurements of radiation are observed, questions are generally raised pertaining to the accuracy and consistency of the measurements. Often the calibration of the sensors used, changes in observers, different measuring techniques, and different platforms for the radiation sensors are reasons why unusual data are often questioned. In this case, the same pilots, using the same aircraft and the same sensors, conducted all BOREAS surveys. The contrast in the observed cosmic radiation data on the 8th and 9th of September, and the definite patterns shown in Figure 1 and 2, says much about the relative accuracy and consistency of the measured cosmic data.

How Rare Are High Cosmic Counts

When the high cosmic counts were encountered the question of how unusual were the cosmic radiation measurements was raised. The NWS system using the up- and down-looking detectors has been operationally used since February 1979. During the past 15 years records of airborne NWS surveys of more than 1,600 flight lines covering portions of 25 states and 7 Canadian Provinces have been stored in an operational data base. The up-looking cosmic radiation records from approximately 14,000 flight line surveys in the data base were reviewed and all counts of 500 or greater were selected (753 cases). None of the 743 cases were observed in Canada or in the northern tier of US states where large counts had been thought possible.

The only locations to have the large cosmic counts were flight lines in the states of California, Colorado, Utah and Wyoming, where most of the flight lines are at elevations much higher than those in the BOREAS study area. Of the 743 selected records only 81 cases have values of 800 or more (with a single high value of 1,022 cpm). Cosmic radiation observed at a high elevation would be expected to have higher counts as a result of less atmosphere above the flight line. A simple plot of the average cosmic cpm versus elevation shows a high correlation between the cpm and elevation.

With no observed cases of cosmic cpm greater than should be expected from the cpm versus elevation plot for all 14,000 historical cases, the occurrence of the high radiation values is very to be very unusual. In a brief discussion with J. Trombka, a NASA Space Physics scientist of Goddard Space Flight Center, he advised that the high cosmic radiation could be a very rarely measured event.

Origin of the Cosmic Radiation

There has not been time to investigate or to discuss the high cosmic radiation values or the patterns that have been observed with many other space and basic physicists. It is noted, that during the BOREAS field campaign in September 1994 heavy aurora borealis activity was observed. J. Trombka suggested that the observed cosmic rays are probably solar protons that originate during solar flares at energy levels of about 100 mev and decrease to the measured values of 3.00 to 5.12 mev due to a process called Brehmstrahlung. He also said that the cosmic rays would align with the magnetic field lines of the earth and thus arrive at the earth in definite patterns. A retired physicist (C. Fields) hypothesized that the changes in the daily patterns in Figures 1 and 2 could possibly be related to changes in the earth's magnetic field due to small shifts in the magma of the earth. The authors are not space physicists and those who may be interested in learning more about the records or in providing them with additional information are cordially invite to contact them.

Effects on Other BOREAS Observation

The occurrence of high cosmic radiation may affect radiation or other measurements by BOREAS investigators. The authors are interested in any studies on the effect of the high cosmic radiation on other measurements.

Bibliography

Carroll, T.R. 1981. Airborne soil moisture measurements using natural terrestrial gamma radiation. *Soil Sci.* 132:358-366.

Carroll, T.R. 1987. Operational remote sensing of snow water equivalent and soil moisture in the United States using natural terrestrial gamma radiation, *J. Int., Asso. Hydro. Sci., IAHS Pub.*

Carroll, T.R., and M. Allen. 1988. Airborne gamma radiation snow water measurements and soil moisture measurements and satellite areal extent of snow cover measurements: A user's guide, Version 3.0., Office of Hydrology, National Service, Minneapolis, MN.

Carroll, T.R., E.L. Peck, and D.M. Lipinski. 1988. Airborne time-series measurements of soil moisture using terrestrial gamma radiation. *Proc. Ann. Conf. Am. Soc. Photogram. Remote Sens.*, St. Louis, MO

Fritzsche, A. E., 1982. The National Weather Service Gamma Snow System Physics and Calibration. NWS -8201 report, The Remote Sensing Laboratory, E G & G, Energy Measurement Group, Dept. of Energy, Las Vegas, NV, Dec.

Peck, E. L., 1992. Airborne Gamma Radiation Measurements of Soil Moisture During FIFE, Activities and Results, Hydrex Final Report, NASA Contract NAS5-30959, April. In FIS.

Peck, E.L., T.R. Carroll, and D.M. Lipinski. 1990. Airborne gamma radiation soil moisture measurements over short flight lines. *Sym. on the First ISLSCP Field Experiment*, Anaheim, CA, American Meteorological Soc., Boston MA, p. 79-84.

Peck, E. L., T. R. Carroll, and D.M. Lipinski. 1992. Airborne Soil Moisture Measurements for First International Satellite Land Surface Climatology Program Field Experiment, *Jour. Geophys. Res.* 97, No. D17, p. 18,961-18,967, Nov 30.

Peck, E. L., and A. S. Hope. 1993. Spatial Patterns of Soil Moisture for the FIFE Study Area Derived from Remotely Sensed and Ground Data. Submitted for 2nd FIFE Special Issue of American Geophysical Research Journal of Geophysical Research, May.

BOREAS

Table 1 COSMIC RAYS MEASURED IN THE GROSS COUNT UP (GCU) AIRBORNE GAMMA RADIATION DETECTOR SEP 1993 TO SEP 1994

	DAY 940908	DAY 940909	DAY 940910	ALL DAYS 1/
SSA AREA w/high counts 2/				
AVERAGE	1389	1420	1383	
STDEV	63.9	37.9	40.8	
NO.	24	30	48	
SSA AREA w/low counts				
AVERAGE	214	233	all	
STDEV	31.0	53.1	high	
NO.	14	14	values	
SSA AREA w/mod counts /4				
AVERAGE	479	695	all	
STDEV	15.8	284.8	high	
NO.	3	9	values	
ALL OF BOREAS w/low counts				
AVERAGE	3/	3/	3/	188
STDEV				20.3
NO.				1643

1/ All BOREAS measurements other than high counts on Sep 8-10, 1994 in SSA.

2/ Over 1,000 cpm

3/ No measurements other than in SSA.

4/ On edge of high count area. Part of flight lines with high counts.

Notes: SSA =BOREAS Southern Study Area

Energy level of GCU detector = 3.0 to 5.12 mev.

Measured values are for flight line and segments of flight lines (bins),

BOREAS HYD-6
Eugene Peck and Tom Carroll
3/14/95 co-PIs

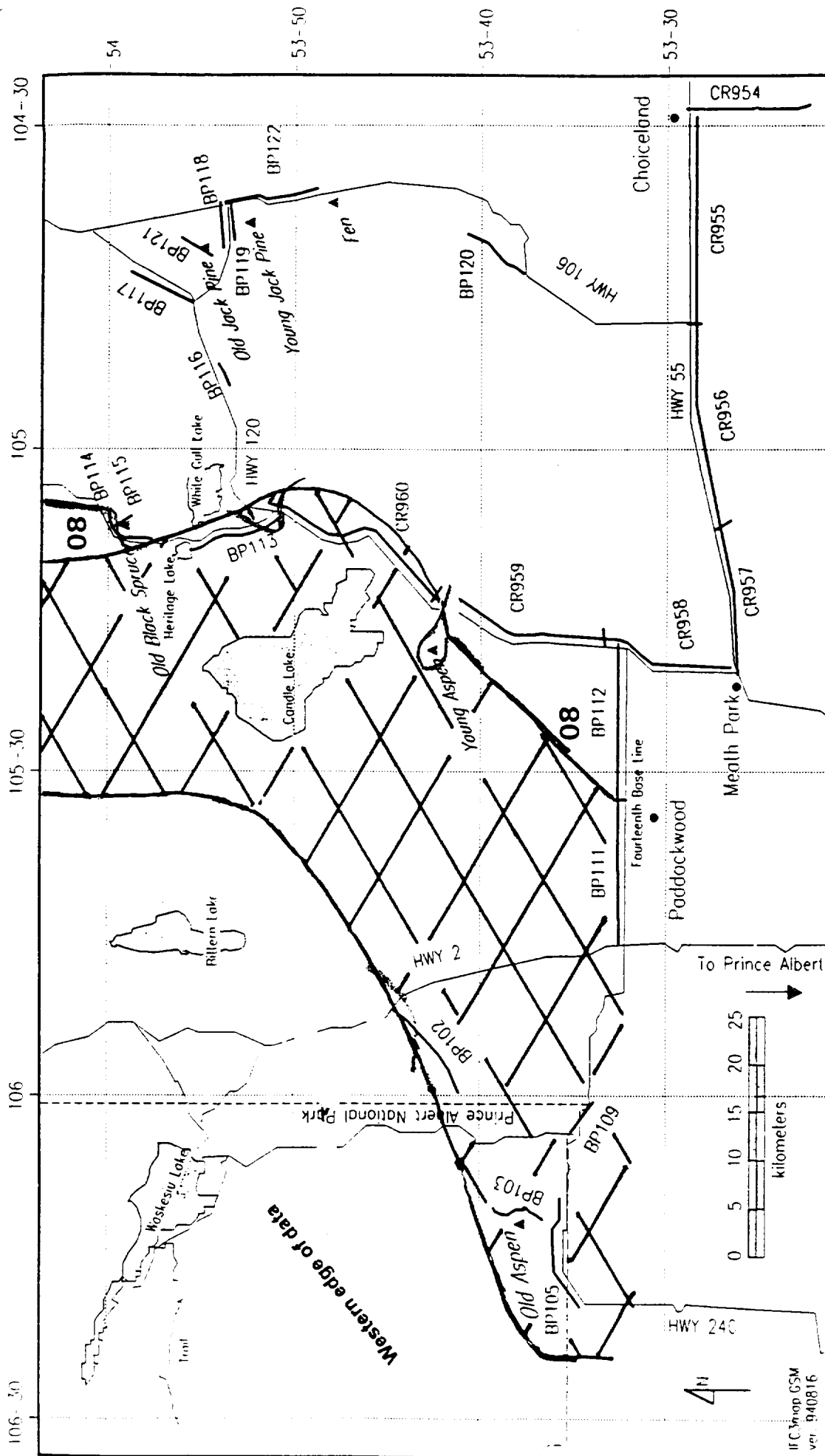


Figure 1. Area of BOREAS Southern Study area with high Cosmic radiation values on 8 September 1994

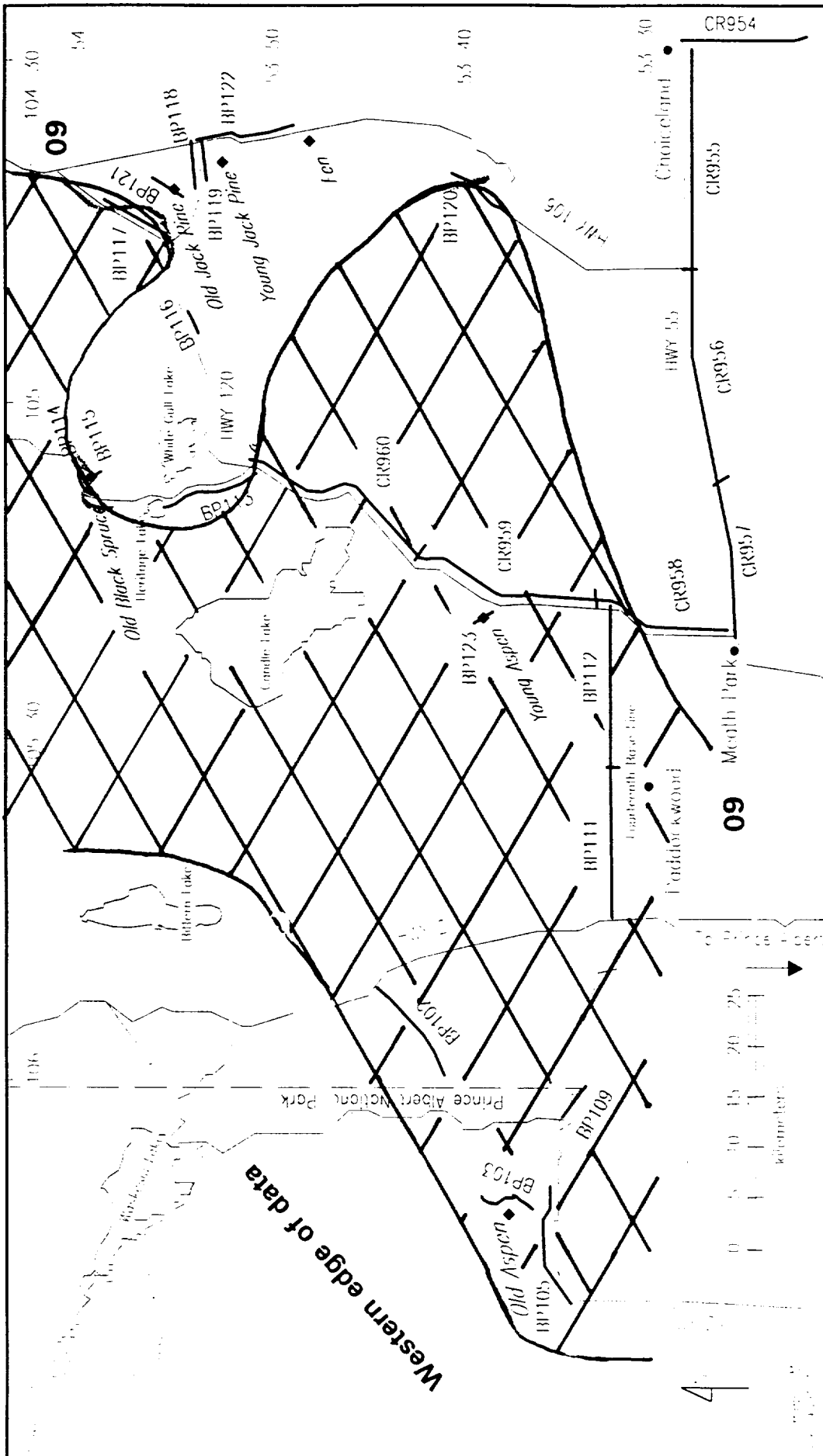


Figure 2. Area of BOREAS Southern Study area with high Cosmic radiation values on 9 September 1994

REPORT DOCUMENTATION PAGE			Form Approved GSA GEN. REG. NO. 27
<small>1. AGENCY USE ONLY (Leave blank)</small>			
<small>2. REPORT DATE</small> May 1995		<small>3. REPORT TYPE AND DATES COVERED</small> Phase 2, Final April 1994 to April 1995	
<small>4. TITLE AND SUBTITLE</small> Remote Sensing of Hydrologic Variables in Boreal Areas, Final Report, Phase 2			
<small>5. AUTHOR</small> Eugene L. Peck Thomas R. Carroll			<small>6. PERFORMING ORGANIZATION REPORT NUMBER</small> NAS5-32336
<small>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</small> Hydex Corporation 2203 Lydia Palce Vienna, VA 22181			<small>8. PERFORMING ORGANIZATION REPORT NUMBER</small> H355
<small>9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES)</small> NASA Goddard Space Flight Center Greenbelt Road Greenbelt, MD 20771			<small>10. SPONSORING MONITORING AGENCY REPORT NUMBER</small>
<small>11. SUPPLEMENTARY NOTES</small> 			
<small>12a. DISTRIBUTION AVAILABILITY STATEMENT</small> No limitation			<small>12b. DISTRIBUTION CODE</small>
<small>13. ABSTRACT (Maximum 200 words)</small> <p>During Phase 2 airborne Gamma Radiation measurements were conducted over 48 BOREAS flight lines. Ground measurements of the soil moisture (SM) of the mineral soil and of the depth and water content (WC) of the moss/humus layer were collected for calibration of the flight lines.</p> <p>Special attention has been given to the flight lines over, and near, the primary tower sites in the southern study area (SSA); Old Black Spruce (OBS), Old Jack Pine, Old Aspen, and Young Aspen. Multiple ground surveys (September 1993, July, August and September 1994) show the variation of the water content of the moss/humus layers and changes in the amount of standing water near the SSA OBS tower during the period September 1993 to September 1994. All ground data, airborne estimates and locations of flight lines and ground sampling points have been submitted to BORIS (Boreas Information System).</p> <p>On 8-10 September 1994 exceptionally high values of cosmic radiation were observed by the airborne gamma radiation system over the SSA. Follow up investigation has not determine the source of, or what caused, the high cosmic count rates.</p>			
<small>14. SUBJECT TERMS</small> Soil Moisture, Remote Sensing, Gamma Radiation Cosmic Radiation, Snow Cover, Moss, Humus			<small>15. NUMBER OF PAGES</small> 28 pages
<small>17. SECURITY CLASSIFICATION OF F</small> Unclassified			<small>16. PRICE CODE</small>
<small>18. SECURITY CLASSIFICATION OF THIS PAGE</small> Unclassified	<small>19. SECURITY CLASSIFICATION OF ABSTRACT</small> Unclassified	<small>20. LIMITATION OF ABSTRACT</small> 	

